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SECTORAL TECHNOLOGY
STRATEGY SERIES

No 10

The Canadian Machinery Sector

SECTORAL TECHNOLOGY STRATEGY SERIES

NO. 10 THE CANADIAN MACHINERY SECTOR

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Highlights

- The machinery sector encompasses equipment used to turn raw materials into finished goods. Depending on the application, there are many subsectors within the sector, such as forestry equipment, metalworking equipment, molding machines, and machine tools for the tool-and-die industry.

- In the global machinery sector there is a major division between the generalist supplier and the dedicated specialist. The generalist operates in several subsectors and is usually large. It conducts product and process development in all its subsectors. The dedicated specialists concentrate on one or a few subsectors and attempt to develop specialized products the generalists cannot readily duplicate.

- Competition is often based on product differentiation, interpreted by differences in technology and overall performance. There can be just as much potential in traditional yet skilful tool-and-die making as there is in computerized robotic equipment. Incremental technology development is extensive, and custom design for specific customers is common in the R&D of small firms.

- The principal competitors of the Canadian machinery sector are the United States, Japan, and Germany. Each, however, has different business and technology strategies. Japan is exceedingly dynamic technologically and is strongly linked to the new manufacturing concept of "lean production." Like the Japanese, the United States machinery sector is characterized by large firms. The German sector, however, has many medium-sized firms, usually dedicated specialists.

- The Canadian sector is nowhere near being able to supply the domestic economy with the machinery vital for economic expansion. The Canadian market is too small to support many indigenous specialized manufacturers. And Canadian machinery firms are too small to mount the marketing required for large-scale exporting. Accordingly, there is a Canadian trade deficit in virtually every subsector.

- The small domestic machinery sector is a serious structural impediment in the Canadian economy. When the Canadian economy expands, Canada's trade deficit increases because domestic manufacturers must import most machinery required. Machinery investment virtually always leads expansion in the business cycle.

- The Canadian sector has some exceptionally creative and entrepreneurial firms, but most are small and unable to conduct significant R&D.

- Canada's strong development of resource industries surprisingly has not led to the development of a strong, related machinery sector.

- The only Canadian machinery subsector with a positive trade balance in 1988 was logging machinery. Four foreign-owned companies dominate the logging-equipment subsector in Canada. Their technology strategies differ; two are dedicated specialists and two generalists. The specialists work more closely with customers to develop innovative logging equipment.

- The problems of the former Canadian firm Massey-Ferguson, once one of the world's leading manufacturers of farm equipment, were the result of indifferent management. Among other things, the firm failed to develop new products; tolerated inefficiencies in production, delays in deliveries, and unchecked shipments; and let relations with dealers deteriorate. Its problems were especially evident in its crucial markets of large tractors and combine harvesters.

- Most of the R&D in the Canadian machinery sector is carried out by indigenous 'threshold' companies who are dedicated specialists. These firms typically have annual sales of about $250 million. The leading ones have strong exports but are not major worldwide suppliers. The six leading threshold firms invest an average of 3.0 per cent of sales in R&D, compared with 0.8 per cent for all Canadian machinery firms. Among firms that perform R&D in Canada, foreign-owned machinery companies spent a mere 1.6 per cent of sales on R&D in 1987, compared with 4 per cent by Canadian-owned firms. Many of the foreign-owned firms lack mandates to perform R&D and export.

- Real R&D spending by Canadian machinery firms declined by almost 25 per cent during the 1980s. The Canadian sector spent barely 1 per cent of its sales revenues on R&D compared with 2.6 per cent in Germany, 1.7 per cent in Japan, 1.5 per cent in the United States, and 3.3 per cent in Sweden.

- A strategy of continual, usually incremental, technology development of high value to customers seems to be the key to growth in machinery sales. Growth firms in this sector need financial support from institutions that recognize the importance of this long-term value-added approach and technology strategy.

- The best growth prospects for the Canadian sector lie in specialized or dedicated machinery products, most of which must be exported to be economically viable for development in Canada. Most Canadian firms lack the resources to market their products globally.

- The sector faces shortages of experienced engineers, managers, and skilled machinists.

- Canada's weak position in machine tools has contributed to the limited scale of domestic machinery manufacturing. Machine tools are a critical part of most machinery manufacturing processes.

- Problems of securing capital, particularly venture capital, are major constraints to firms that want to grow. A great deal of capital is required for marketing and distribution. It may thus be prudent for these firms to seek capital from their major customers and suppliers. This would help build credibility with the more usual sources of capital. Executives in this sector tend to find the banks and other sources of capital to be unsophisticated in assessing their technological requirements and capabilities.

- For many small Canadian machinery companies, developing and selling prototypes of new products is tantamount to risking the future of these companies. The costs of prototypes are not allowed for R&D tax credits. The current Scientific Research and Experimental Development section of the tax incentive program should be re-examined, reworded, or reinterpreted to recognize that R&D in this sector is often different from that in many other sectors.

- Canadian machinery firms should improve their planning by including technology development in their business plans; provide better technical training; promote and assist partnerships with universities, colleges, and governments; take advantage of government assistance programs; build close working relationships with key customers; and assess the potential of a trading company to help market Canadian machinery globally.

Background to the Sectoral Technology Strategy Series

In the emerging "new" economy of the 1990s, successful high-value businesses in advanced nations are being driven by innovation, propelled by spending on new products and processes. Their business strategies centre increasingly on specialized knowledge and skill in finding the right "fit" between their unique blend of core technologies and particular markets.

Where does Canada stand in this rapidly evolving new environment of changing linkages and relationships? The poor innovative capacity of Canadian industry has long been a concern of the Science Council of Canada, going back to its 1971 report *Innovation in a Cold Climate*. The Council re-emphasized this concern in 1988. It focused its attention on the potential for action at a sectoral level in its statement *A Sectoral Approach to Innovation*. It argued:

> There is growing recognition by industry and government in Canada of the key role played by technology and R&D in domestic and international competition. The Science Council considers that it is primarily the responsibility of industries to raise the degree of domestic technological sophistication and the level of R&D. Nevertheless, governments can help business to sustain long-term competitiveness both by building partnerships with individual firms and by generating consensus on the formulation of innovation strategies for the various industrial sectors. The intent is not for government to tell business what to do, but to facilitate business cooperation in a process of self-help. The process of building consensus on a strategy for a particular sector will involve close and on-going consultation with industries about the current role of technology and R&D in the sector, the opportunities foreseen, and the nature of the sources, stimuli, and forms of technological innovation. Obviously, to be successful, separate innovation strategies will be needed for each sector. The Science Council hopes that the process of building consensus will generate commitment and collective will concerning priorities, areas for cooperation, and agenda for action.

This statement proved to be an important step in the path that subsequently led the Council to undertake a major Sectoral Technology Strategy project.

In 1989, Industry, Science and Technology Canada, at a time of heightened concern for the state of Canadian competitiveness and serious questioning about the low level of Canada's gross expenditures on research and development as measured against other advanced countries, agreed to provide the main funding for this project. It also stipulated the selection of sectors on which it would like the project to focus.

Each report in this Sectoral Technology Strategy Series draws in part upon analyses commissioned by the Science Council of Canada from contractors, designed to reveal the key dynamics driving technological innovation in the sector and influencing company technology strategies. Each report has also benefited considerably from the comments and advice submitted by the many external reviewers from business, universities, and government, who are recognized in the Acknowledgements.

Commentary on the Sectoral Technology Strategy Series and R&D Targets

The Sectoral Technology Strategy Series has analysed 15 Canadian sectors. On the basis of this experience, the Science Council of Canada makes the following points with regard to Canadian R&D performance and the issue of setting sectoral R&D targets.

- Canadian firms, when grouped by sectors, generally perform much less R&D than their trade competitors. Using the indicator of R&D as a percentage of sales, Canadian firms undertake R&D at a rate about one-third to one-half the rate of their leading international sectoral competitors. The notable exception among those sectors analysed is telecommunications.

- In some product lines or specific technologies certain absolute threshold levels of R&D and capital investment must be reached if the effort is to be considered to have a chance of making a commercial payback. High thresholds are apparent in some parts of sectors such as telecommunications (central office switches), automotive parts ("Tier 1" supplier status), oil and gas (reformulated gasoline standards by refineries), and electronics (integrated circuit foundry). Such absolute thresholds cannot be clearly expressed as a percentage of sales.

- The reasons for the lower level of R&D spending by firms in most of the 15 Canadian sectors are: choice of business and technology strategy (which, in part, leave Canadian companies as essentially non-participants in many higher value-adding segments); the relatively small size of Canadian firms; the high absolute thresholds of R&D expenditure required to be a meaningful player, especially for innovative technology strategies; and the degree of foreign ownership of Canadian firms (especially important in the case of the automotive vehicles and parts sectors).

- The lack of R&D relative to other countries affects Canadian competitiveness, but it is only one of many factors, such as capital and labour costs, quality design, good marketing, and management, that interact to affect overall competitiveness. Nevertheless, the contribution of R&D, or more precisely, technology-based innovation, is becoming more pronounced throughout the global economy and Canada continues to fall behind. The low level of R&D is especially detrimental to the capacity of Canadian resource-based sectors to compete with higher-value, differentiated products, leaving them vulnerable to adverse shifts in costs beyond their control, such as a higher exchange rate.

- Major potential does exist for Canadian industry to make additional R&D investments. However, fulfilling this potential depends heavily on the vision and capability of management to make strategic use of technology, to speed the firms' innovation process, to work more closely with suppliers and "demanding customers" all the way to the end of the product chain, and to build core capabilities in incremental innovation and R&D. Canadian firms have not yet fully grasped the implications of the emerging new "lean enterprise" or "agile producer" strategy. To follow this new strategy involves seeking to offer maximum value to customers. It requires integrating the skills base of a knowledgeable workforce with flexible management structures that stimulate cooperative initiatives within and between firms to match customer needs.

- The dominant technology strategies being followed by Canadian firms in these sectors are of adopt and adapt. Innovation technology strategies are not very extensive (telecommunications is again an exception) and hardly any firms focus on breakthrough strategies to enhance competitiveness. Overall, these 15 sectors show little attempt at diversification out of existing product lines as opposed to making such products more efficiently.

- Governments can set sectoral R&D targets in the hope of stimulating enhanced industrial performance, shifts in business strategy, and greater commitment by the private sector to R&D. However, private sector R&D is only meaningfully undertaken in conjunction with a full complement of associated private and public sector actions ranging from improved design and production to finance and marketing. Doing more R&D will not be productive unless linked to a broader corporate technology strategy that is carefully designed to support the firm's business objectives. Otherwise, the corporation cannot, and will not, marshal the complementary investments required to reap the benefits of the R&D. It is the firm that must commit R&D resources.

- Setting sectoral R&D targets becomes more difficult as the boundaries between sectors are breaking down, through technological advances, regulatory change, and firm restructuring. Larger and more diversified firms that dominate modern industrial R&D perform R&D that might be allocated to any of several sectors. Examples include the textiles and materials R&D performed by large Japanese steel firms, the electronics R&D by automotive-vehicle firms, and the software R&D by telecommunications firms. Canadian governments have quite correctly encouraged higher levels of industrial R&D in Canada. In view of the rapid pace of scientific advances and technological change, plus the role of system interdependencies and synergies between technologies, setting R&D targets does not appear to be a task warranting the intensive effort, cooperation, and, ultimately, commitment that would be required by federal and provincial governments and private sector organizations.

List of Sectoral Technology Strategy Series Reports

No. 1 The Canadian Telecommunications Sector
No. 2 The Canadian Automotive-Parts Sector
No. 3 The Canadian Iron and Steel Sector
No. 4 The Canadian Automotive-Vehicle Sector
No. 5 The Canadian Oil and Gas Sector
No. 6 The Canadian Petrochemicals and Resins Sector
No. 7 The Canadian Banking Sector
No. 8 The Canadian Nonferrous-Metals Sector
No. 9 The Canadian Forest-Products Sector
No. 10 The Canadian Machinery Sector
No. 11 The Canadian Food and Beverage Sector
No. 12 The Canadian Electric-Power Sector
No. 13 The Canadian Consulting-Engineering Sector
No. 14 The Canadian Electronics Sector
No. 15 The Canadian Computer Software and Services Sector

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Introduction

The products of the machinery* sector vary greatly — ranging from agricultural machinery to equipment for water and waste treatment or materials handling. Throughout its variety of products, however, incremental technology development is critical and extensive.

A characteristic of the global sector is the small amount of mass production and low average batch size. Most products are made in batches of fewer than 50 items. This affects the technology and production organization, which must respond to pressures for great variety and the specific needs of customers. Information technology, particularly computer equipment, has permeated the sector and helped develop efficient batch production. Much development in modern flexible machinery systems has combined mechanical and information technologies and linked many activities such as design, production setup, lean production, and marketing, to form an automated system.

The Canadian machinery sector has some exceptionally creative and entrepreneurial firms, but most are small and find it hard to develop further or undertake any significant R&D.

The principal objectives of this report are to identify the technology strategies of leading Canadian firms and to compare the sector's R&D performance with its major competitors. The report also explores reasons for any differences in R&D performances and the effect they might have on competitiveness.

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* Throughout this report "machinery" refers to "nonelectrical machinery." The electrical-machinery sector is discussed in Science Council of Canada Sectoral Technology Strategy Series, No. 12: *The Canadian Electric-Power Sector*. Few differences in technology strategies exist, however, between the Canadian electrical and nonelectrical machinery subsectors.

The Global and Canadian Machinery Sector

Machinery can be broadly defined as equipment used by industry to produce, process, assemble, or manufacture goods. Machinery products are not in themselves end-products for mass markets; rather, they are a series of intermediate goods from which end-products are produced. These end-products, of course, vary enormously. They may be as simple as a bale of hay or a frying pan, or as complex as a jet airliner. They may be made of everyday materials such as wood, plastic, steel, or aluminum, or of less common substances such as titanium, carbon fibre, or diamond. The role and purpose of the sector is to produce physical equipment that is used in the process of transforming raw materials into finished products.

The term *machinery sector* embraces many products. Nevertheless, the sector as a whole has several general characteristics:

- Sales tend to be highly cyclical, and sales in the machinery sector are a leading business-cycle indicator; orders for machinery pick up if business leaders in general think the economy will expand. Conversely, a decline in machinery orders generally signals a recessionary trend. The degree to which the machinery sector influences business cycles and therefore profoundly influences the Canadian economy overall is explored below.

- Machinery products are sold on the basis of their value to the businesses that will use them. This means that there are fewer but more sophisticated customers for these products than for manufactured goods as a whole. In general, customer firms can easily distinguish between machinery they can use and cannot use. Machinery must perform as advertised. Although promotion and marketing are important, the machine must perform in the field.

- Technology is a major factor in the success or failure of firms in the sector. For the more advanced technology firms, it is a dominant factor in business performance.

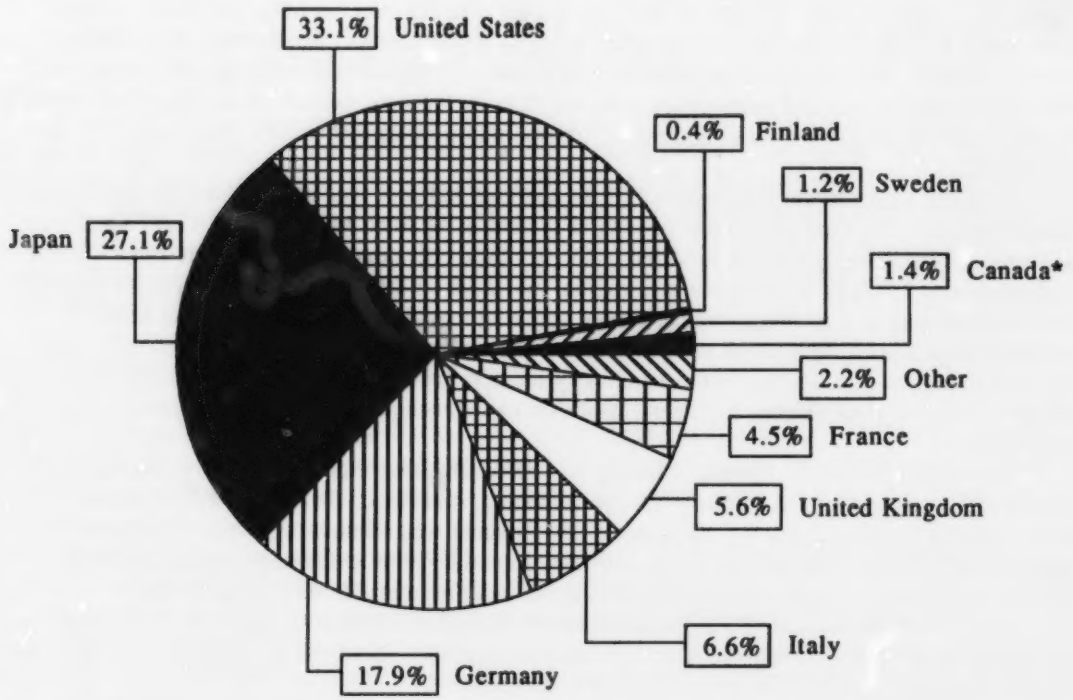
Among nations in the Organization for Economic Co-operation and Development (OECD), the machinery market is dominated by the United States at 33.1 per cent, followed by Japan at 27.1 per cent and Germany at 17.9 per cent (Figure 1). Although the United States remains the largest producer, its share has recently dropped quite dramatically. Germany and Japan, however, continue to carve out larger global market positions. While the real compound annual growth rate in machinery production during the 1980s declined 1.6 per cent in the United States, it increased 5.7 per cent in Germany, and 2.1 per cent in Japan.

Contributing to the domination of world markets by the United States, Germany, and Japan has been their large domestic markets. However, the technological and economic development of each of their machinery sectors can be traced to different patterns in the evolution of their respective economies.

The U.S. Machinery Sector

The U.S. machinery sector remains the most diversified in the world. It is active in virtually all major subsectors including machinery for agriculture, raw material extraction and processing, construction, manufacturing (including tool-and-die making, metal machining, plastics and moulds), and advanced manufacturing systems (including robots and computer-controlled systems). In addition, the U.S. sector

Figure 1. Dominant OECD producers of machinery, by value of shipments (1987)



Source: Commission of the European Communities, "Panorama of EC Industry 1990," and Statistics Canada

* Total 1987 OECD shipments were C$732 billion

has developed highly advanced machinery for space and defence, such as ultraprecision parts, machines to handle specialized materials, and aerospace products. The U.S. sector also benefits from the many multinational firms that produce various machines — for example, Caterpillar for construction equipment, John Deere for agricultural machinery.

In the United States, major industrialization at the beginning of the 20th century, coupled with a large domestic market, allowed the development of specialized equipment in much of the machinery sector. Pioneering mass production, notably automobile manufacturing, not only provided an impetus to tool-and-die making, metal machining, and motorized production lines, but also stimulated new oil drilling and processing machinery, and even construction techniques. The United States was at the leading edge of process technology and had a large enough domestic market to support the simultaneous development of numerous variations in equipment. Today, the U.S. industry remains the dominant world player and continues to produce the widest variety of equipment. It is, however, losing some of its share to Germany and Japan, albeit for different reasons.

The German Machinery Sector

The German sector also developed with general industrialization in the early 20th century. However, its domestic market was not as large as the U.S. market, and the process of industrialization was slower. Mass production of consumer durables, such as appliances and automobiles, occurred later than in North America. As a result of the smaller market and later industrialization, German industry became more specialized and more export-oriented than its U.S. counterpart. It developed strong links with the metal-working, chemicals, and public transportation industries (such as railroads and, later, automobiles).

A major factor in the development of the German industry was its close ties to the national education system. The German worker education system is regarded as one of the world's strongest, and it produces a steady stream of knowledgeable machine operators and machine designers. Typically, a student spends 1.5 days in company classrooms, two days on machines in the company training centre, and one day at a nearby technical school studying machine theory. This system exposes apprentices to industrial operations such as tool-and-die making, small instrument mechanics, and metal machining. In this way the entire machinery industry had a good supply of technically trained personnel. Even for professional engineers, hands-on experience with shop-floor production was encouraged.

A key concern of the German industry has been achieving high quality, meaning superior performance at any given cost to justify its specialization; otherwise, cheaper generic equipment would suffice. Another factor influencing the sector's development was eliminating waste. Compared with the United States, Germany had to import far more raw material. High levels of precision, together with the ability to process and handle materials with exactitude, has considerably reduced waste.

After 1945 German machinery manufacturers capitalized on the reconstruction of Europe and the new European Common Market. They continue to command more of the global market than the combined shares of their British, French, and Italian rivals.

German firms tend to be medium sized, unlike the American and Japanese. In 1989 West Germany accounted for more than 40 per cent of the value of European Economic Community's machinery production. This is equivalent to more than 50 per cent of the United States or about 65 per cent of the production in Japan.

The Japanese Machinery Sector

The modern Japanese machinery sector has been largely built around the new concept of "lean manufacturing" or "lean production." In essence, this technique minimizes or eliminates waste. Materials are processed so that the finished product is produced with minimum raw material. Human labour is reduced and restructured to maximize production by machines. Human resources are reserved for more demanding tasks or for tasks in which human skills are more applicable (for example, work involving judgement or design).

In practice, this requires a highly automated process, involving machinery that is controlled mainly by computers and the use of robots to move materials and finished products. Lean production is a total system — a process beginning with raw material and ending with a final product.

The technological demands placed on machinery equipment suppliers in this lean production environment are the most stringent in the world. But enhanced technology is not the only demand of lean production. Automated machinery is only of value if it is properly installed and operated. Thus new management skills are needed. Lean production is the key contributor to the technological superiority the Japanese car industry enjoys over its U.S. and European counterparts (see Science

Council of Canada Sectoral Technology Strategy Series, No. 4: *The Canadian Automotive-Vehicle Sector*).

The success of the Japanese automobile, together with other industries, in global markets has provided Japanese machinery producers with opportunities to exploit economies of scale. In fact, they are not dissimilar to the U.S. machinery industry in the 1920s — at a leading edge of technology and profiting from a large market that can support the simultaneous development of many and varied machines.

Although the Japanese have skilfully implemented a highly successful managerial system, applicable to many industries, it is noteworthy that the German industry has grown faster. The greater specialization of the German sector has provided more opportunities to penetrate the machine market.

The Japanese sector, however, is now second in size only to that of the United States. In addition, the latter is declining at 1.6 per cent annually, while the Japanese sector is growing at 2.1 per cent. As the Japanese expand their investments overseas, the opportunities for Japanese machinery manufacturers will grow.

The Canadian Machinery Sector

Growth of the Canadian machinery sector has been constrained because in the past 30 years Canada has lagged behind most developed countries in producing, developing, and using machinery. Canada's investment as a percentage of Gross Domestic Product (GDP) from 1960-1988 was 7.3, compared with the OECD average of 8.6.

The Canadian sector accounts for only 1.4 per cent of total OECD nonelectrical machinery shipments, and production growth in Canada is a relatively weak 0.5 per cent annually (Figure 2). This rate is closer to the low U.S. rate than the high rates of Japan and Germany. Moreover, it is considerably lower than the growth in Canada's GDP which was 4.4 per cent during the same period (1980-1989). The Canadian machinery sector is clearly not keeping pace with the economy as a whole.

Regardless of the measure employed, the machinery sector is one of Canada's weakest industrial performers. The sector contributes a mere 0.7 per cent to Canada's GDP.[1] In contrast, this sector represents 2.1 per cent of the GDP in the United States, despite negative growth over the last 10 years. The sector contributes 1.49 per cent of Canadian industrial GDP, compared with 2.92 per cent of the OECD industrial GDP.

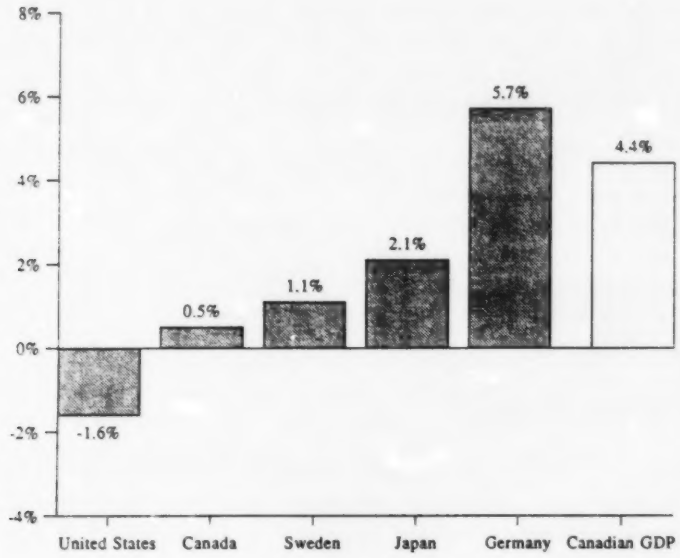
Canada is a small and unimportant player in they global machinery sector. It holds only a 1.4 per cent share of the OECD market and less than 5 per cent of OECD exports (Figure 3).

The relatively small domestic market in most subsectors of the sector means that companies that fail to export cannot be competitive. Without this competitiveness, many Canadian companies cannot afford research labs, pilot plants, and advanced manufacturing processes. It is a vicious circle. It can be broken only by good management and innovative ideas.

In addition, high levels of foreign ownership in key industrial sectors, such as petrochemicals, automotive, and manufacturing, means that foreign head offices make many purchasing decisions, effectively downsizing an already small domestic market. However, the Free Trade Agreement now greatly diminishes the constraint of the limited domestic market.

Owing to a historical tendency to focus on the domestic market, Canadian machinery companies have integrated horizontally, as part of large diversified conglomerates. These companies have failed to build economies of scale in any one subsector. The result is that there are now only dedicated specialists, with no generalist firms based on low-cost manufacturing.

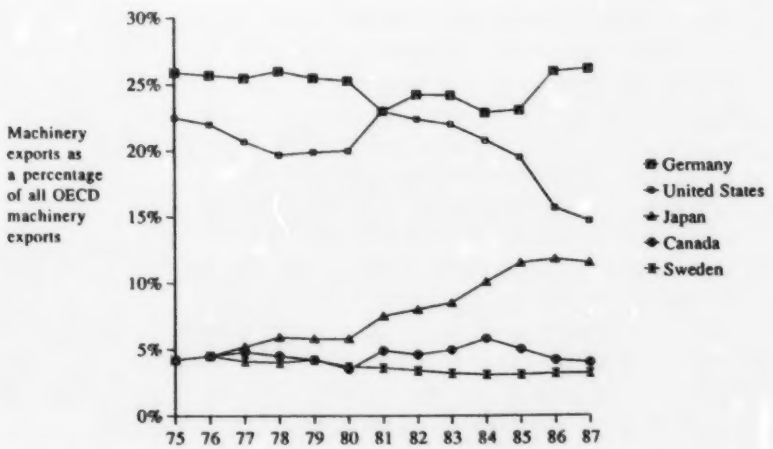
Figure 2. Real compound annual growth rate of machinery production (1980-1989)



Source: Canada Consulting Cresap analysis of data from the Commission of the European Communities "Panorama of EC Industry 1990," IMF, and Statistics Canada

Note: The compound annual growth rate was calculated using production figures in local currency deflated using the local industrial product price deflator. Canadian GDP growth and Japan's production growth are for 1980 to 1988; Sweden's growth rate is for 1980 to 1987.

Figure 3. Trends in machinery exports as a percentage of OECD machinery trade (1987)



Source: Canada Consulting Cresap analysis of data from OECD Foreign Trade by Commodities, 1987

The few larger Canadian machinery plants tend to be highly specialized to obtain scale economies in the production of standard off-the-shelf machines or equipment. They are almost entirely rationalized parts of multinational firms. However, in some subsectors, including metal-rolling mills and welding equipment, the competitiveness of Canadian subsidiaries of U.S. companies, which have access to parent technologies, is constrained because the U.S. technology is not as advanced as that of the Japanese and Germans.

Canada's development of resource industries surprisingly has not stimulated the development of a strong, related machinery sector. One reason for this is that Canada's resource-based machinery industries have long been unusually open and vulnerable to outside competition. Unlike much Canadian manufacturing, they operated with virtually no tariff protection. Canadian farmers and the mining and forestry companies earlier this century won special tariff treatment from the government in respect of their machinery purchases. This special low tariff reduced their machinery costs and thus boosted their competitiveness. In most of the Canadian resource-based machinery subsectors, imports have a very high market share. Only the forestry and power-generation equipment industries have managed to hold on to close to half of their domestic markets.

The machinery sector faces shortages of experienced engineers, managers, and workers. The weak apprenticeship system in Canada has contributed to a shortage of skilled tradespeople. The sector views the system in Germany with some envy. There, 60 to 70 per cent of students go into apprenticeship programs. After three years of training, students either become full-time machinists or graduate to technical college to become machine designers.[2]

The current situation in Canada is distressing. At a time when the number and ability of workers (for example, in problem solving and statistical process control) are rising, the interest in skilled-trades education is declining. One Ontario study reported that despite a 6.6 per cent increase in enrolment at Canadian high schools from 1985 to 1988, registration in technological studies decreased 12 per cent.[3]

Although Canadian universities turn out well-rounded mechanical engineers, machining companies have to invest two to three years in on-the-job training before the engineers become qualified machinery designers.[4] But because of the small number of machinery companies, it is hard to justify implementing design of a system that would alleviate the shortage of people experienced in design, development, and use of machine tools, control system robotics, and rotating machinery design.

Canada's weak position in machine tools has contributed to the limited scale of domestic machinery manufacturing. Machine tools, particularly flexible manufacturing systems, are critical to most machinery manufacturing processes.

The repercussion of this weakness is far-reaching. Canada has fewer skilled machine operators than its leading trade competitors, and training is more expensive and less available. Machine-tool technology is not always on the leading edge, and companies cannot benefit from the knowledge transfer that occurs when working closely with the supplier or by serving as a test site. Distributors are less knowledgeable and less able to provide good service because machinery and parts must be shipped from overseas.

Growth of machinery firms has also been inhibited by the lack of venture capital in Canada. Canadian investors prefer short-term, risk-free investments. This makes it difficult to raise enough capital to pursue long-term innovative ventures that would increase market share and access export markets.

Exacerbating the dearth of venture capital, Canada's high interest rates and high taxation mean fewer viable investments. Canadian companies do not have the same incentive to invest in manufacturing facilities, even to grow through mergers or acquisitions, as do firms in countries where capital costs and taxation rates are lower.

Canada's Trade Balance in Machinery Subsectors

Because the machinery sector encompasses such a variety of products, any detailed analysis of the industry in Canada, and elsewhere, requires it to be disaggregated into major subsectors.

The machinery sector in Canada is composed of several subsectors, the largest of which are materials handling, fluids handling, mechanical power transfer equipment, and agricultural equipment (Table 1).

Table 1. Subsectors of the Canadian machinery sector

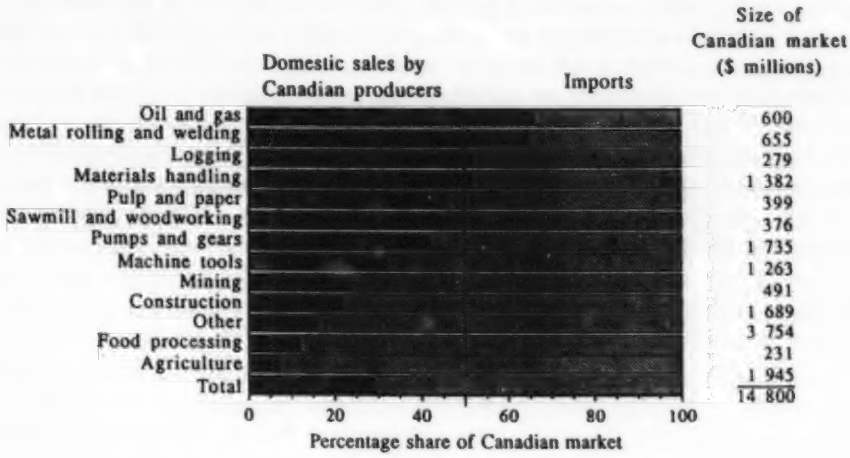
Machinery subsector	Estimated 1988 shipments ($ million)	Percentage of total Canadian shipments	1986 export-import ratio by subsector*
Materials handling	1 617	9.7	0.38
Fluids handling/mechanical power transfer	1 211	7.2	0.39
Agriculture	966	5.8	0.60
Plastics machinery and moulds	942	5.6	0.95
Machine tools	927	5.5	0.22
Construction	737	4.4	0.30
Metal rolling and welding	674	4.0	0.19
Logging	503	3.0	1.95
Oil and gas	408	2.4	0.85
Sawmill and woodworking	403	2.4	0.25
Pulp and paper	371	2.2	0.33
Mining	178	1.1	0.50
Food processing	77	0.5	0.32
All other	7 727	46.2	0.28
Total	16 741	100.0	0.34

Source: Statistics Canada and Industry, Science and Technology Canada

* Ratio of exports to imports. A figure of 1 means exports and imports were equal; less than 1 means imports were greater. The total ratio of 0.34 means Canada is exporting barely a third as much as it imports.

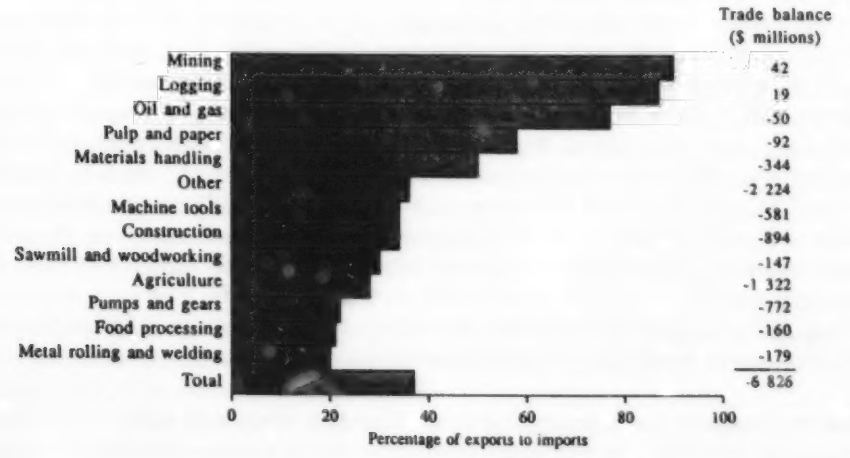
Seventy-one per cent of the machinery sold in Canada is imported (Figure 4). Indeed, in 1988 every industry subsector, with the exception of logging machinery, had a negative balance of trade. There are, however, some export strengths in the oil and gas, mining, and plastics machinery and moulds subsectors (see Figure 5 and note that "Plastics Machinery and Moulds" is included under "Other" in figures 4 and 5).

Figure 4. Canadian machinery market consumption (1987)



Source: Canada Consulting Cresap analysis of data from Statistics Canada 31-203, ISTC 1988 Industry Profiles, and ISTC Manufacturing Trade and Measures, 1981-1987

Figure 5. Percentage of exports to imports by machinery subsector (1986)



Source: Canada Consulting Cresap analysis of Statistics Canada and ISTC data

Note: 100 per cent of exports indicates balanced trade.

This negative trade balance in most subsectors is a major structural impediment to the Canadian economy. As the economy moves toward an upswing in the normal business cycle, Canadian manufacturers and service firms, anticipating growth, order machinery to expand capacity. The result is a deterioration in the Canadian balance of payments, since such a high proportion of the machinery that is purchased has to be imported. On the other hand, as other countries move toward an upswing in the business cycle, there are, of course, no corresponding export gains in Canadian machinery.

The situation is not improving over time. A Science Council of Canada study[5] published almost 10 years ago noted that the machinery sector's import-export ratio was particularly poor. Even in 1980 Canada covered only a third of its imports with exports — virtually the same proportion as today.[6] It noted that Canadian firms were too small to market globally, though some were successful, including Prairie agricultural machinery firms.

Machinery Imports and Canadian Growth Limits

The weakness of Canada's machinery sector presents a problem for Canadian economic growth. In the latter half of the 1980s, researchers using computer simulations experimented "on paper" with different Canadian growth scenarios.[7] The objective of these simulations was to improve understanding of how technological factors influence the Canadian economy.[8] In almost every simulation, researchers observed investment funds flowing out of Canada to pay for imported machinery. Similar results have been obtained by other organizations using different models.

Further simulations were based on enhanced productivity in the Canadian economy. These simulations incorporated the positive results from additional industrial R&D. The model was run with selective changes in industrial investment patterns, simulating increased R&D expenditures, and also with enhanced productivity obtained through selective changes in input-output coefficients.

Although subject to the general limits of econometric analysis, the results were noteworthy. The simulations showed that enhanced productivity did lead to GDP growth, but it also exacerbated the balance of payments deficit brought on by machinery imports. The extra growth in the Canadian economy had a disproportionately negative impact on the balance of payments. The usual outcome, for Canada, of a deterioration in the balance of payments is a rise in interest rates. The model automatically reacted this way. In fact, under most simulations, and despite higher overall growth, unemployment actually increased. The extra output, generated by the higher productivity, led to subtle changes in the internal capital-labour ratios within the Canadian economy. The economy grew, but at the cost of becoming even more capital-intensive and, surprisingly, creating greater unemployment.[9]

Of course, econometric simulations are subject to error. No one can say with complete assurance that the changes introduced into the model, or even the underlying principles of the model itself, accurately reflect the operations of the Canadian economy. Nevertheless, any changes in the structure of the economy that provoke a rise in real interest rates can be expected to harm the economy's potential growth.

The simulations suggest that there may be some surprising limits to the Canadian economy's growth potential — unless the negative trade balance in this one sector can be reversed or at least reduced.

To identify prospects for improvement in the Canadian machinery sector, it is necessary to consider the nature of innovation in machinery production and to discover what is preventing Canadian machinery firms from growing more rapidly.

The Nature of Technological Change in the Global Machinery Sector

Machinery companies are being driven to improve their technology by customer demands for better service and higher-quality, higher-performance products; by increased competition due to fewer trade barriers; and by the need to increase the scale of their operations to support worldwide distribution. This puts a premium on innovation. Innovation is also being driven by rising labour costs and environmental regulations.[10]

Companies can innovate by taking advantage of new manufacturing technologies, such as flexible manufacturing systems and computer-aided design and manufacturing. Advances in electronics and robotics are creating additional opportunities to develop new solutions to customer problems.[11]

Competitive advantage for companies in the machinery sector is gained through product differentiation or by manufacturing-process improvements.

Product Differentiation

Depending on the machinery subsector, a practical rule of thumb suggests that customers will pay from 5 to 20 per cent more for superior product quality, features, performance, and service. For instance, in pulping machinery, the premium ranges from 5 to 10 per cent.[12] A better piece of equipment thus has "leverage" on the output for the final consumer. This rule varies substantially according to a product's merit. Nevertheless, product differentiation is a key to success.

The primary means of distinguishing products in the machinery sector is through the development of sophisticated features that are difficult for other companies to duplicate. For example, in 1978 Caterpillar developed an elevated sprocket to drive the tracks of its largest bulldozers. The design extends component life, is easier to service, and improves performance. Twelve years later, rival firms still had not introduced similar products. The result is that Caterpillar has sold 25 000 elevated-sprocket bulldozers and captured 50 per cent of the market for large bulldozers.[13]

Companies also differentiate themselves by developing a range of products. Caterpillar, for instance, has doubled the size of its product line since 1984.[14] And a Canadian company, Groupe Denis, says it was able to win a contract with the USSR because it can supply an entire line of high-performance logging equipment.[15]

In response to the need to differentiate products, the pace of product development and introduction has accelerated. In 1989, John Deere either updated or introduced new products for 60 per cent of its worldwide product line — the largest number of new products in the company's 152-year history. At its Welland, Ontario factory, the development time for an extension to its product line has been cut almost in half, from three years to just over 18 months.[16]

However, companies can reach a limit on how frequently they can change their products. New products often entail additional costs for manufacturing equipment, spare-parts inventories, and training for manufacturing, marketing, sales, and service staff.

Process Improvements

The second principal means of creating competitive advantage is through advances in technologies that reduce production costs and improve quality.

At John Deere, for example, one manufacturing cell equipped with integrated equipment and systems now produces a component that used to be routed through 43 different work stations. Because the component can now be manufactured more quickly, the company's inventory of this component has been trimmed from 43 days to three days, and costs have been reduced as a consequence.[17]

In another example, Caterpillar cut costs by 35 per cent by consolidating into one cell all the machinery, welding, and assembly of motor-grader front axle parts — a task formerly carried out in four different buildings.[18]

The Generalist Supplier Versus the Dedicated Specialist

There is a major division in the global machinery sector: the generalist supplier versus the dedicated specialist. As the name implies, a generalist operates in several subsectors. The dominant characteristic of the generalist is its large size, which is necessary to develop products and improve processes in several subsectors simultaneously. In contrast, a dedicated specialist concentrates on either one or a few subsectors and develops specialized products that the generalists, however large, cannot readily duplicate. On the whole, the U.S. and Japanese strategies are generalist, and the German is specialist. It is not surprising, therefore, that the U.S. and Japanese sectors are characterized by very large firms, and the German sector has a larger number of small- and medium-sized firms.

Although some specialists are large firms, virtually all small companies are specialists. Small companies usually produce custom-engineered equipment or a variety of product lines with short production runs. This allows flexibility or large specialized machines whose fabrication involves long lead times.

The success of both generalists and specialists is measured by their technological performance. The generalist differentiates products by offering lower prices through sophisticated processing. The specialist differentiates products by their uniqueness. Technology is a determining factor regardless of approach.

There are pros and cons associated with either strategy. An examination of three specific subsectors (logging equipment, construction equipment, and agricultural equipment) reveals the strengths and weaknesses of the two approaches.

Logging Equipment Companies

The global logging-equipment subsector is dominated by four companies that control 60 per cent of the market. Finnish-owned Rauma-Repola holds 22 per cent of the market (its Canadian-based subsidiary, Timberjack, accounts for 58 per cent of that share); Finnish-owned Valmet, 13 per cent; U.S.-owned agricultural-equipment manufacturer John Deere, 15 per cent; and U.S.-owned construction equipment giant Caterpillar, 10 per cent (Table 2).

Within this subsector, there is a difference between the technology strategies of the dedicated companies, whose primary business is logging and forestry equipment, and John Deere and Caterpillar, whose primary business lies elsewhere.

Because of a lack of scale, dedicated companies cannot compete with John Deere and Caterpillar in manufacturing-process technology. Consequently, they compete by out-sourcing major subcomponents, such as engines and axles, and by using their logging expertise (in consultation with customers) to develop products better suited to client needs.

John Deere and Caterpillar, on the other hand, are not interested in working with customers to customize products with an initially low manufacturing volume. Their strategy is to incrementally improve existing products and rely on their worldwide distribution networks for competitive advantage.

Table 2. Market shares of the leading logging-equipment companies

Firm	1989 logging equipment revenue (C$ millions)	Market share %	Country of ownership	R&D/ sales %	Technology strategy§	Main company product area
Rauma-Repola*†	433	22	Finland	1.1	Innovate	Paper mills
John Deere†	300	15	U.S.	4.8	Adapt	Agricultural equipment
Valmet	265	13	Finland	3.5	Innovate	Paper machines
Caterpillar†	200	10	U.S.	2.0	Adapt	Construction equipment
Groupe Denis‡	26	1	Canada	2.1	Innovate	Logging equipment
Harricana†	22	1	Canada	2.7	Innovate	Logging equipment
Other	754	38				
Total	2 000	100				

Source: Canada Consulting Cresap Interviews and annual reports

* Rauma-Repola gets $250 million in revenue from its Timberjack subsidiary, which is based in Canada and has the worldwide R&D, marketing and manufacturing mandate for Timberjack products.
† R&D/sales ratio for entire company
‡ Largest Canadian-owned logging-equipment manufacturer
§ For more detail see appendix

As the pace of change accelerates, however, dedicated logging manufacturers could increase their market share. John Deere and Caterpillar have already lost shares by allowing dedicated producers to go unchallenged in emerging product markets. Dedicated manufacturers, for example, have developed delimber and feller-buncher machines that automate the process of cutting trees and removing branches, thus allowing one machinery operator to do the work of four or more workers with chain saws.[19]

Valmet, which had a compound annual growth of 27 per cent from 1985 to 1989, has aggressively acquired logging-equipment companies throughout the world. The company formed a joint venture with the Soviet Union to develop new products, and it also developed new forwarders and frame-steer loader products.[20] Valmet is a company that has so-called forward integrated into marketing and "positional" differentiation. That is to say, it is using its presence in several countries, through mergers and joint ventures, to promote its products.

Rauma-Repola's technology strategy uses its broad forestry expertise to develop innovative logging equipment. Although it is the world's largest logging-equipment supplier, logging equipment accounts for only about 13 per cent of the company's total sales.[21] In addition to forestry equipment, the company has large pulp-and-paper mills, sawmills, and woodworking firms. It is noteworthy, however, that the company follows the value-added processing chain through the entire forest and forest-products sector. It is a vertically integrated firm.

Vertical integration allows Rauma-Repola to leverage its forestry expertise and make products better suited to its own and its customers' needs. Because other parts of its forestry operation provide guaranteed customers for its equipment, the company reduces the risk of investing in new products and manufacturing facilities. In addition, because of its size, Rauma-Repola supports a large research facility for developing of a full line of products (ranging from logging to pulping equipment) that it uses to supply other such integrated forest-product companies. Rauma-Repola's strategy is not without risk, however. In-house demands could cause the company to lose touch with other logging-equipment customers, and the creative tension driving product innovation might be diffused or diluted by having a guaranteed customer.

Construction Equipment Companies

In the construction industry, the odds are against the small or specialized innovator. Only the largest construction-machinery companies, such as U.S.-based Caterpillar and Japan-based Komatsu, can afford the substantial investment to develop sales and marketing and to implement the process technology improvements required to compete globally. The critical difference between the logging- and construction-equipment subsectors is the number of customers. Although there is a limited number of customers in the logging industry (since there is a limited number of large and suitable forests), there are many construction-equipment companies and an equally large number of clients throughout the world.

Because customers are concerned mainly with a company's ability to deliver high value products and follow-up service, large dealer networks are a key factor of success in the industry. For example, Caterpillar's dealers are generally much larger than competing dealers and, therefore, able to offer customers superior service and financing.

Although product innovation does provide competitive advantage, it is often wasted if the company cannot support and service sophisticated new products in the field. Even when small companies are first to develop innovative products, larger firms can design similar products and bring them to market faster because the small companies lack strong worldwide distribution networks. Moreover, superior process technology enables larger companies to manufacture the products at a lower cost and higher quality than small innovators. Superior process technology, in effect, signifies that the large generalist firms are moving toward lean manufacture or lean production.

As *BusinessWeek* observed, Caterpillar, the world's largest construction-equipment company, is rarely the first to create new products for its markets. It allows other companies to go through the trial-and-error process of introducing products. After these trials, it introduces the most trouble-free product into the market.[22] The company has invested heavily in process technology, spending large amounts since 1976 to modify its plants and purchase capital equipment to improve manufacturing processes.[23]

Komatsu, the world's second largest construction-equipment company, has increased capital investment to 5.1 per cent of sales.[24] It recently opened a showcase computer-integrated manufacturing facility for small industrial machinery. The facility is providing Komatsu with experience in innovating advances in manufacturing technology. The facility also incorporates a

technical centre that will speed the development of new products that take advantage of the manufacturing facility's flexibility.

Based on its innovation technology strategy, Komatsu has several world firsts: a radio-controlled amphibious bulldozer, an underwater rubble-levelling robot, fine-plasma cutting machinery, and an exterior-wall-installing robot, to name a few.

Looking toward the future, Komatsu sees electronics, robotics, and engineering polymers as emerging technologies that will play a critical role in the development of stronger, lighter, and more productive new machinery.

Agricultural Equipment Companies

The agricultural-equipment industry was buffeted by weak demand throughout the 1980s. Owing to low demand and profitability for agricultural products, farmers deferred equipment purchases. For instance, the average age of tractors in the field increased from seven years to 15 years in the 1980s.[25]

This demand for agricultural machinery resulted in overcapacity, which in turn led to price erosion. John Deere, for example, was once able to charge a 10 to 20 per cent price premium because of its high-quality products and service. That premium has now been squeezed to 5 per cent.[26]

Problems in the industry have elicited a variety of responses from firms.

John Deere, the only full-line manufacturer of agricultural machinery, did not cut R&D spending drastically despite the industry "contraction" of the 1980s. The company was thus able to release several new products in the late 1980s. Furthermore, it decentralized R&D into factories focused through worldwide product mandates. For example, John Deere's Welland, Ontario plant has the mandate to design, develop, manufacture, and market farm tractor loaders, rotary cutters, manure spreaders, and a five-wheeled utility vehicle.

Building on its experience in the construction-equipment industry, Caterpillar developed a tractor line with a bulldozer-like rubber track. These tractors match the speed and mobility of four-wheel drive tractors while providing better traction and less soil compaction. Introduced in the United States in 1987, the tractors are now sold throughout Europe and North America. The tractor line has been so successful that Caterpillar has been unable to satisfy the demand.

Case and International Harvester were purchased by Tenneco and merged to achieve a competitive market share and economies of scale in R&D, manufacturing, and distribution. The acquisitions and merger have resulted in a variety of product line combinations. Frequent product changes, however, have made it difficult for the company's distributors to stock repair parts.

Varity (formerly Massey-Ferguson) consolidated its tractor production in Europe to take advantage of the higher demand and lower productions costs of the company's small tractors.

The problems of the former Canadian firm Massey-Ferguson, once one of the world's leading manufacturers of farm equipment, were the result of indifferent management. In the 1970s, Massey-Ferguson decided to pursue other lines of business, confident that it could supply industrial and construction machinery through a diversification strategy. At the same time, the company neglected its primary business of producing farm machinery. The firm failed to develop new products; tolerated inefficiencies in production, delays in deliveries, and unchecked shipments and let relations with dealers deteriorate. The company also probably suffered from a deteriorating debt-equity ratio. Such problems were especially evident in two markets crucial to the company's success — large tractors and combine harvesters. When the company failed to stay abreast of the competition, sales tumbled because farmers became more selective. In 1982 the Ontario and Canadian governments saved

the company from bankruptcy. In 1990 they agreed to let it move its headquarters out of the country, in an attempt to increase the company's profitability by realizing U.S. income tax losses.

There is a role for both the generalist firms and the dedicated specialist firms. The fewer the potential customers, the better the prospects for the specialist firms, although they have limited growth prospects.

R&D and Technology Strategies in the Canadian Machinery Sector

A major factor in the performance of the Canadian machinery sector is that there are simply no indigenous multinationals. Only Caterpillar Canada (a subsidiary of Caterpillar U.S.) has sales of more than $250 million annually.[27] It does no R&D in Canada. Much R&D in the Canadian machinery sector is carried out by indigenous "threshold" companies, those with sales ranging between $25 and $250 million.[28] They are dedicated specialists. Although the leading threshold companies have strong export sales, they are not dominant worldwide suppliers. On the other hand, they are large enough in their areas of specialization to maintain significant R&D efforts.

The six leading indigenous threshold firms (Husky, Hymac, Timberjack, Harricana, Groupe Denis, and CAE Machinery Ltd.) invested an average of 3.0 per cent of sales in R&D, compared with 0.8 per cent for all Canadian machinery firms (Table 3). This level of investment exceeds the 1.8 per cent R&D sales ratio of the 30 threshold firms in all sectors performing R&D in Canada.[29]

Table 3. R&D of the leading indigenous threshold firms in Canada

Company	1989 machinery R&D spending ($ millions)	1989 machinery sales ($ millions)	R&D sales %
Husky Injection Molding	9.4	173*	5.4
Hymac	2.5	69	3.6
Timberjack	4.4	250	1.8
Harricana	1.2	46	2.6
Groupe Denis	1.0	47	2.7
CAE Machinery Ltd.†	0.8	30	2.7
Total threshold firms (6 firms)	19.3	615	3.0
Total all machinery firms	78.0‡	10 062§	0.8

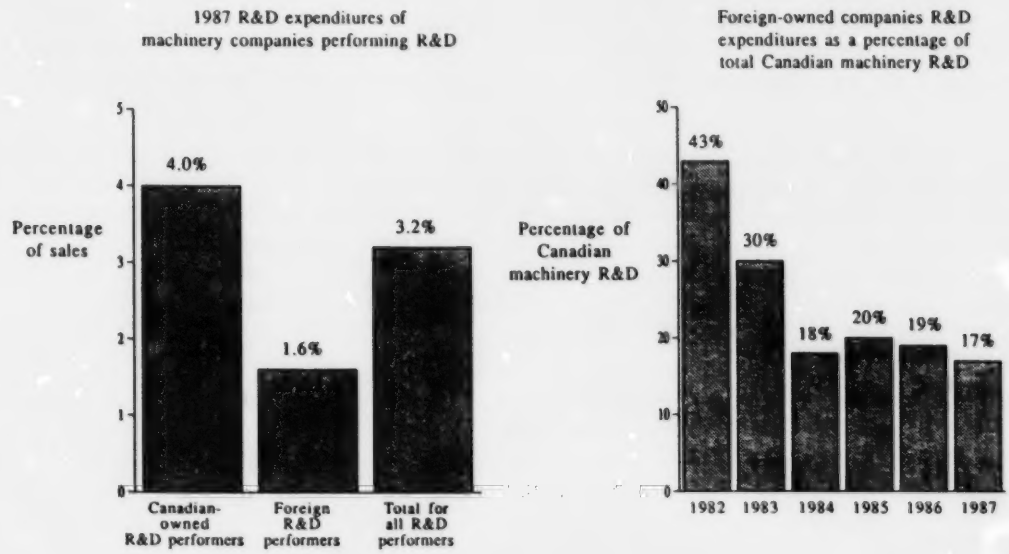
Source: Canada Consulting Cresap analysis of data from Statistics Canada 88-202, and 31-001, Industry Interviews, and annual reports

Note: Leading indigenous threshold firms are a subset of all threshold firms. They are Canadian owned, invest in much R&D, and have strong exports. But they cannot be classified as dominant worldwide suppliers.

* Includes moulds, machines, and robots
† CAE Machinery is a subsidiary of CAE Industries Ltd.
‡ Total of 247 performing firms R&D
§ Total of 1908 machinery firms

Foreign-owned machinery companies have not made large R&D investments in Canada. Among machinery firms conducting R&D in Canada in 1987, they spent a mere 1.6 per cent of sales on R&D, compared with the 4 per cent expended by Canadian-owned firms. Moreover, foreign-owned companies' share of R&D spending declined from 43 per cent of Canadian-machinery R&D in 1982 to 17 per cent in 1987 (Figure 6). The level of foreign ownership in the sector is high, and many foreign-owned firms have lacked mandates to perform R&D and to export. Foreign subsidiaries accounted for 53 per cent of total sales in Canada in 1988.

Figure 6. R&D spending: foreign- versus Canadian-owned companies



Source: Canada Consulting Cresap analysis of data from Statistics Canada 88-202

Note: The graph of companies performing R&D does not include sales of companies not performing R&D.

In contrast, the world's largest machinery companies spend heavily on R&D — 3.6 per cent of sales.[30] None of these firms is Canadian. They are typically low-cost producers, with well-established distribution systems and well-known brand names. These companies are usually concerned with maintaining market share, while gaining leverage from their distribution networks and large-scale manufacturing. Most importantly, they tend to concentrate R&D near their home base or their largest markets. They are thus attuned to their customers' needs. The Japanese automotive-vehicle industry is one example of a major client industry for machinery. This sector is restructuring worldwide around the Japanese concept of "lean manufacture,"[31] which requires a close relationship with machine-tool firms and related R&D. But it is impossible for Canadian industry to duplicate this scale of research and production.

Smaller Canadian firms with less than $25 million in annual sales generally lack the financial resources to undertake significant R&D, and their localized distribution network reduces the leverage they can gain from R&D investments. In some cases, small companies that performed R&D in the past and failed to reap benefits from it are now reluctant to make any R&D commitments.[32]

Most firms, many of them small, perform no R&D; including 96 per cent in the turbine and mechanical power subsector; 89 per cent in sawmills and woodworking; 89 per cent in construction and mining; 87 per cent in compressors and pumps; and 84 per cent in logging and other specialized equipment.[33] It is important to understand that the average size of Canadian machinery companies is 60 employees. According to one industry executive, these firms are too busy during a business cycle upswing to worry about R&D, then lack the money for R&D investments as the economic cycle turns downward. Smaller machinery firms are particularly vulnerable to the seasonal and cyclical demand for machinery, which produces many cash flow problems.

Six machinery companies account for 25 per cent of the Canadian sector's total R&D spending, and only 13 per cent of companies in the sector do any R&D. The few small firms that invest in R&D, however, do so aggressively. The 217 small firms that conducted R&D in 1988 allocated an average of 4.4 per cent of sales to R&D (Table 4). Although much research is oriented toward custom designs for specific customers (a limiting factor in its applicability for tax credits), it does represent notable activity of potential development of the Canadian sector.

Table 4. R&D investments in Canada

Company size	Number of R&D performers	1988 sales of R&D performers ($ millions)	1988 R&D spending ($ millions)	R&D/sales (%)	R&D firm ($ millions)
Small ($0 - $25 M)	217	1 172	52	4.4	0.2
Threshold ($25 - $250 M)	30	1 633	30	1.8	1.0
Foreign multinational (>$250 M)	0	0	0	0	0

Source: Canada Consulting Cresap analysis of research commissioned from Statistics Canada

Note: There is one foreign multinational, Caterpillar, with Canadian sales greater than $250 million. There are no indigenous Canadian multinationals.

There appears to be some agreement among executives that a minimum level of R&D is needed to remain competitive; however, it is difficult to determine what this threshold level should be for a given product.

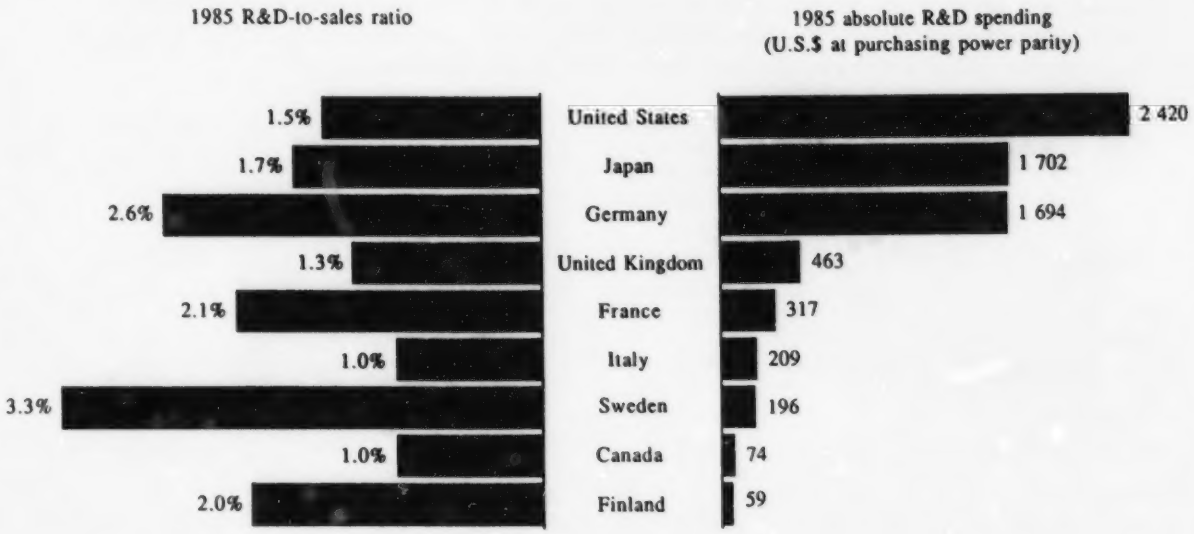
The concept of minimum threshold R&D spending levels may be understood best in the context of product line. It is not very meaningful in comparing competitors' total R&D spending. Companies may compete in the same industry subsector, but often have very different product lines. Nevertheless, it is noteworthy that the leading global companies, such as Caterpillar, Komatsu, and

John Deere, generally maintain R&D spending levels despite fluctuations in sales revenues.[34] This indicates that these companies appreciate that they need to maintain threshold levels of investments.

Canadian Machinery R&D: Comparisons and Limitations

Canada lags behind most countries in R&D spending on non-electrical machinery, both in absolute and relative terms. The Canadian sector spends just 1 per cent of its sales revenues on R&D, compared with 2.6 per cent in Germany, 1.7 per cent in Japan, 1.5 per cent in the United States, and 3.3 per cent in Sweden (Figure 7).

Figure 7. Global spending on R&D in the machinery sector



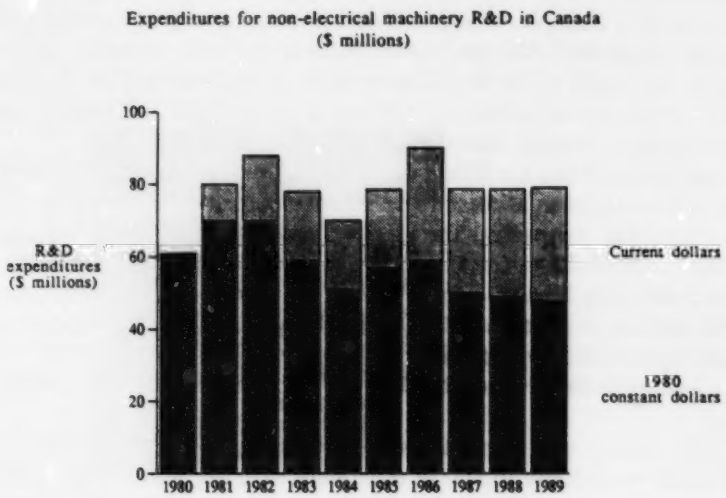
Source: Canada Consulting Cresap analysis of data from OECD Science and Technology Indicators Report No. 3, *OECD Industry Structure Statistics*, and Statistics Canada 88-207 and 31-203

Note: French R&D-to-sales ratio includes R&D spending for office and computing machinery.

Moreover, real R&D spending in Canada actually declined by almost 25 per cent during the 1980s (Figure 8). The Canadian R&D sales ratio rises and falls with economic cycles. It is currently at a 15-year low (Figure 9).

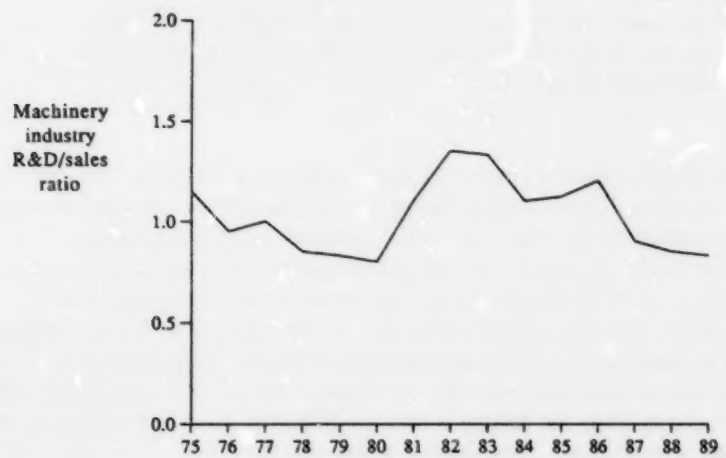
Relative to foreign multinationals, Canadian threshold companies such as Husky, Hymac, Harricana, and Groupe Denis do spend extensively on R&D. The number of threshold companies

Figure 8. Real R&D spending on machinery in Canada (1980-1989)



Source: Canada Consulting Cresap analysis of data from Statistics Canada 88-202

Figure 9. Canadian R&D-to-sales ratio (1975-1989)



Source: Canada Consulting Cresap analysis of data from Statistics Canada 88-202

jumped from 23 to 30 at the peak of the business cycle between 1987 and 1988, and their R&D spending increased from $24 million to $30 million (Figure 10).

Several Canadian machinery firms develop new products and some even conduct basic or general applied research. For example, at Zenon Water Systems one group is responsible for product development, while the corporate R&D group is responsible for basic research. Zenon addresses the full spectrum of R&D, and much of the firm's innovation comes from within. In contrast, the evolution and creative improvement of mining vehicles at Jarvis Clark is development-oriented and driven primarily by customer demands. Both are successful strategies.

Large domestic demand has not stimulated domestic machinery supply. Despite a large domestic demand in subsectors such as forestry or mining equipment, there are no large Canadian-owned multinational companies. The largest Canadian-owned forestry-equipment companies are Hymac, with sales of $80 million, and Groupe Denis, with sales of $46.5 million. However, these figures are small compared with Finnish-owned Valmet and Rauma-Repola, which have sales of $1.9 billion and $602 million, respectively. The largest Canadian-owned agricultural and construction machinery companies are dwarfed by Caterpillar's 1989 sales of $10.9 billion and John Deere's 1989 sales of $6.3 billion.[35] To raise the level of R&D in the machinery sector will probably require more threshold companies.

There are many reasons why Canada has failed to produce indigenous multinational machinery companies. These include an inability to realize economies of scale; reliance on natural resources to provide competitive advantage; lack of skilled workers; an inability to take advantage of applied research; a weak position in machine tools; and expensive capital financing.

Case Studies: Technology Strategies of Canadian Firms

The technology strategies available to Canadian machinery companies are summarized in Table 5, which assesses some of the strengths and weaknesses of each strategy.

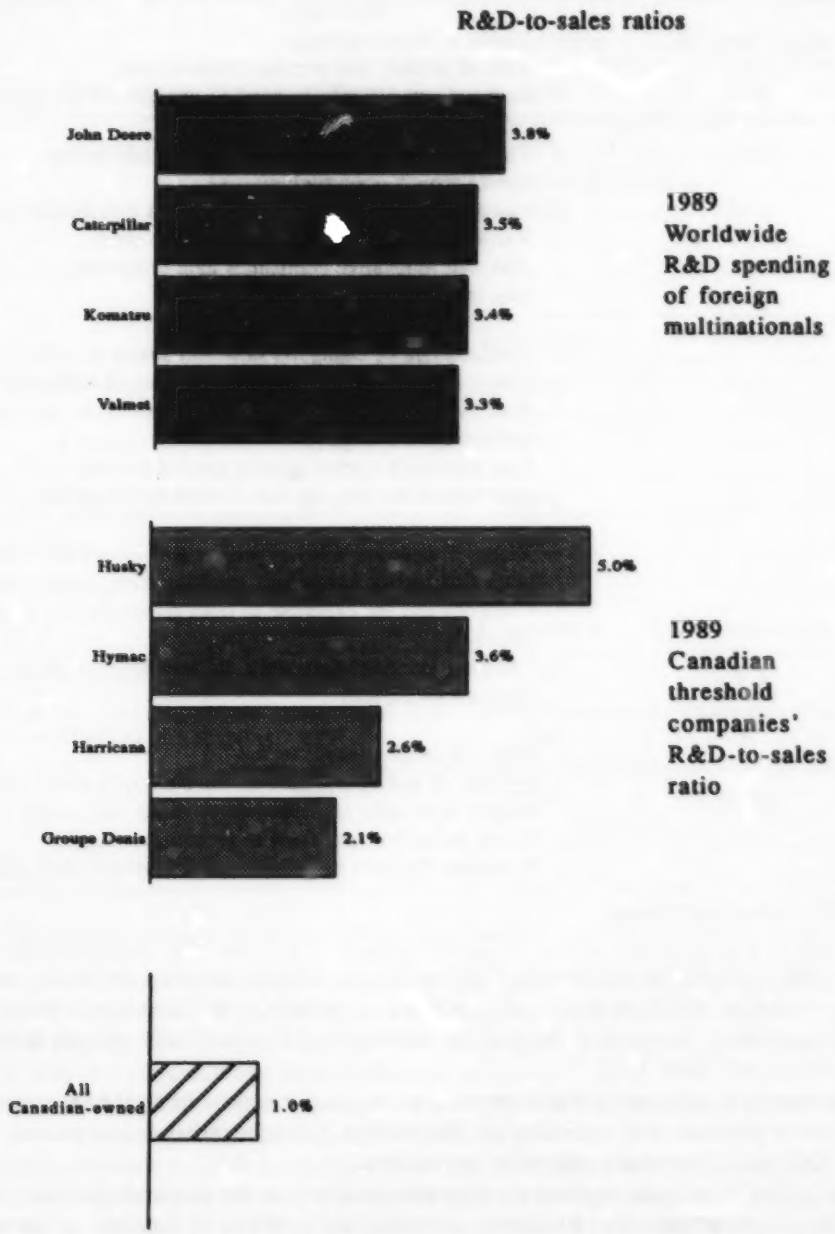
The following case studies show the different technology strategies of three successful Canadian companies. Hymac, a supplier of pulp-and-paper machinery, is strongly oriented toward product innovation and breakthrough; Husky, a manufacturer of plastic-injection moulding machinery, maintains a blended approach between customer-driven product and process innovation, and product adaptation, innovation, and breakthrough; and Timberjack, a logging equipment supplier, focuses on product innovation adaptation (Figure 11).

Hymac

Hymac is a Quebec-based supplier of pulp-and-paper machinery. Its sales have risen dramatically from $3 million in 1975 to $80 million in 1989. During the 1980s, Hymac emerged as one of the three dominant firms in an industry that had eight major companies at the beginning of the decade. Sunds-Defibrator controls 65 per cent of the global pulp processing equipment market, Hymac 18 per cent, and Sprout-Bauer (currently for sale by its owner ABB) 17 per cent.[36]

Lacking access to the amounts of equity capital that allowed Sunds-Defibrator and Sprout-Bauer to expand by acquiring other firms and their technologies, Hymac grew by developing its own technology and products. Most of this growth was funded from its own operations, although it received some R&D grants from the federal Industrial Research Assistance Program of the National Research Council and several loans from Quebec's risk-sharing fund.

Figure 10. R&D spending by Canadian threshold companies compared with spending by foreign multinationals



Source: Canada Consulting Cresap interviews and company annual reports

Table 5. Technology strategies for Canadian machinery firms

Technology strategy	General assessment for nonelectrical-machinery companies
Do nothing	• Viable in short term only • Risk of product and process obsolescence • Reduced capability to respond to unexpected changes in the industry
Adopt	• Viable in industries with long product life cycles • Limits growth opportunities • Viable if competitive advantages are in distribution not product • Viable if product development cycle is short • Risk that innovative companies gain proprietary advantages or are able to sustain better profitability
Adapt	• Viable if rate of change is slow and strong development skills exist • Viable if cost of innovation exceeds loss of adaptation • Risk in industries with short product life cycle and rapid technological change • Risk that rapid market growth spurred by innovative technologies may happen too fast for non-innovators to capitalize
Innovation	• Viable if there are ways to protect technology and capitalize on other first mover advantages resulting from higher-value products • Company has the expertise to react quickly to the innovations of others • Company provides a dynamic environment and attracts the best and brightest employees
Breakthrough	• High risk, high reward • Difficult to justify payback on the basis of a single product but long-term benefits of follow-on products may justify investment • Patent protection necessary to protect investment • Company develops an infrastructure that may take years to duplicate

Source: Canada Consulting Cresap

From 1985 to 1990, Hymac invested $10 million in R&D to develop technologically superior products for a market in which product quality and proven reliability are the chief criteria of customers. The success of the strategy is evident: two-thirds of Hymac's sales growth derived from new products developed since 1983.[37]

Hymac currently allocates about 6 per cent of its sales revenues to an R&D program that develops innovative products and technologies. The company's strategy has led to several world firsts, including the HXD-64, a two-stage pulp-refining machine.

Hymac's first large-scale product-development project was the single-disk refiner. Hymac launched the $4 million project after its licence to market the products of Finnish company, Jylhavaara, in Canada ended in 1983.

Figure 11. Company technology strategies

		Adopt and Adapt	Innovation	Breakthrough	
Hymac	**Product**	10%	50%	20%	**80%**
	Process	10%	10%	0%	**20%**
		20%	**60%**	**20%**	

		Adopt and Adapt	Innovation	Breakthrough	
Husky	**Product**	15%	25%	10%	**50%**
	Process	15%	25%	10%	**50%**
		30%	**50%**	**20%**	

		Adopt and Adapt	Innovation	Breakthrough	
Timberjack	**Product**	55%	15%	5%	**75%**
	Process	15%	10%	0%	**25%**
		70%	**25%**	**5%**	

Source: Canada Consulting Cresap interviews

With yearly sales of only about $15 million, Hymac faced the daunting task of developing its own single-disk refiner. Drawing on engineering experience gained from developing other products, and from its licence agreement, Hymac produced a refiner based on a bleached chemi-thermomechanical pulping (BCTMP) technology. This technique offers higher yields than chemical processes and causes less fibre damage than mechanical processes.

Although very risky, the project was successful. As a result, Hymac has captured more than 50 per cent of the worldwide market for BCTMP refiners.[38]

Its heavy investment in R&D is complemented by its organizational structure. The organization empowers product development managers and marketing managers to initiate or make design improvements to products, and it encourages all employees to innovate. In addition, the company relies on its network of engineers and service personnel to solicit ideas from customers for product improvements.

Husky Injection Molding

Husky Injection Molding is an Ontario-based manufacturer of plastic-injection moulding machinery. These machines produce high-volume products such as margarine tubs and two-litre pop bottles. The firm controls 80 per cent of Canada's market for high-capacity injection moulding machines.

Husky spends approximately 5 per cent of sales on R&D in an attempt to remain two years ahead of the competition.[39]

The company develops only products that are cosponsored by a customer. The air ejection system pioneered by Husky shows how customer needs drove a simple, low-cost product improvement that gave Husky a major competitive advantage.

The $200 000 project produced the world's first four- and 16-cavity air ejection systems. Ejecting finished plastic products out of a mould with air is quicker than mechanical ejection. It also allows the manufacture of thinner products that cool faster and use less plastic. Until the Husky system was introduced, however, air ejection could not be used for the kinds of multiple-cavity moulds demanded by high-volume producers — when one unit popped off, the air that escaped depleted the pressure available to eject other parts. Husky overcame this problem by installing an accumulator on the injection moulding machine to store compressed air. The increased air flow was enough to pop off four units simultaneously. By constricting specific parts of the air-flow channels, Husky increased capacity to 16 units.

Timberjack

Timberjack was a private Canadian company acquired by Finnish forestry-products manufacturer Rauma-Repola in June 1989. Canada remains Timberjack's home base, however, and it has the world product mandate for equipment servicing full-tree logging applications.

Timberjack had originally been purchased by Canadian management in 1984 from Eaton-Yale (a U.S. truck-axle manufacturer), with the help of Sequoia Associates, a U.S.-based venture capital firm. In its five years of Canadian ownership, Timberjack more than doubled its revenues through a combination of developing and buying technology and acquiring companies with good products, such as Koehring Waterous and Peerless.

Timberjack has 15 per cent of the worldwide forest-equipment market and spends 1.8 per cent of its sales on R&D.[40] Unlike many of its competitors who make a range of machinery products, Timberjack focuses on logging equipment such as skidders, feller-bunchers, and delimbers.

Investment in new products focuses on packaging improvements for subcomponents, such as engines, drive-trains, and hydraulics to meet customer needs better. For example, Timberjack developed a more flexible, lower-cost delimber that uses rubber tires instead of steel tracks.

Timberjack also developed the 2500 series of feller-bunchers. This series has a tiltable cab that remains level when the machine is on a slope. They can operate on slopes as steep as 50 per cent (compared with 28 per cent for conventional feller-bunchers), and can swing completely around within the area of their own tracks so that surrounding trees are not damaged. As a result of its technology strategy, Timberjack is the world's top producer of feller-bunchers, with a 30 per cent share of the market.

Growth Strategies for the Canadian Machinery Sector

Problems in the Canadian Sector: The Missing Elements

Much government policy in the sector during the past two decades has focused on reducing the trade imbalance. The government has established mechanisms for import substitution to build stronger links between the resource and machinery sectors — for instance, between mining and machinery firms of between forest-products and machinery firms — and taken general measures such as tax credits to stimulate R&D to help develop better products and promote exports. The lack of strong links, between resource companies and resource-based machinery companies in particular, has almost certainly hurt both groups of sectors. The mutually beneficial synergy between a vibrant domestic machinery manufacturer and, say, the pulp-and-paper sector is still missing.

The machinery sector remains very small but is active in developing new products. The degree of innovation varies from company to company. Some development activity in Canada is customized, and most is both very specialized and constrained by marketing limitations — Canadian machinery firms are too small to finance global marketing programs. They lack the scale, visibility, and R&D support of more high-technology firms in sectors such as telecommunications.

R&D Support

R&D in the machinery sector tends to concentrate on incremental improvements, customized development, and new product development rather than on basic or applied research. Firms could benefit from government incentives that recognize this focus better.

The market served by the machinery sector is very pragmatic, in the sense that it purchases technologies with practical benefits. For example, adding "smart" electronic operator-controls to farming, mining, or other off-road vehicles greatly improves ergonomics, fuel consumption, economy, and vehicle life. However, the introduction of such features follows a steady incremental order as the marketplace agrees to try the new feature, not as the machinery firm develops a new product or process. Accordingly, firms in the smart-controls market must advance their knowledge of state-of-the-art control concepts. They must spend funds to work closely with their customers to judge the time required to develop and introduce the next stage of the product.

Unfortunately, firms find that the Canadian government generally does not assist these R&D activities financially, either with tax credits or regional support programs.

Similarly, for many small Canadian machinery companies, developing and selling prototypes of new products is tantamount to risking their futures. Small organizations in this sector do not have the resources of large, multinational firms, such as Caterpillar or John Deere, who can build several prototypes solely for field testing or for "friendly" customers to debug.

Unfortunately, once again, the costs of customer prototypes are not allowed for R&D tax credits. The critical pre-marketing effort to support new product development, and service and warranty costs incurred by debugging in the field are as much a part of experimental development in the machinery sector as laboratory tests are in other sectors. When a development engineer makes a design decision, the only recourse is to release the design and to "suck it and see," an expression often heard in the engineering manager's office. The success of these creative designs is measured by the amount of redesign and marketing subsequently required, plus servicing and warranty costs, to transform the prototype into a commercial product, preferably with sustained export levels. These

problems tend to be similar to those in the Canadian automotive-parts sector (see Science Council of Canada Sectoral Technology Strategy Series, No. 2: *The Canadian Automotive-Parts Sector*).

Some machinery firms have found that Revenue Canada will accept some of the costs mentioned above as legitimate R&D expenditures. Yet others have found that prototypes are disallowed as R&D tax credits.[41] It appears that the current Scientific Research and Experimental Development section of the tax incentive program is too research-oriented. It should be re-examined, reworded, or reinterpreted to recognize that R&D in the machinery sector is often different from R&D in many other sectors. Clarifying the wording in the tax incentive program is important if the Canadian government is to strengthen the machinery sector through R&D support. Finally, removing ambiguity on eligibility would also help make preparation of the claims easier.

Access to Capital

To become a world-class competitor, a Canadian machinery firm must have a product development program that is not eroded or abandoned to protect short-term profits. This is not easy for a small firm faced with the problems of a seasonal and cyclical market.

A company can succeed and become profitable in a local market with "me-too" (adopted and adapted) products before initiating advanced product work and attacking world markets. This is a low-cost strategy. It may be suitable in the face of North American investors' typical desire for short-term, quarterly and annual, profits. But successful Canadian machinery firms seeking long-term growth do not follow this model and cannot afford to follow it. At an early stage they must offer products with distinctive traits and superior performance, something that Canada's few threshold machinery firms have found. This long-term strategy is typical of those backed by patient Japanese investors.

A strategy of continual, usually incremental, technology development seems to be the key to growth in machinery sales. Growth firms in this sector need support from financial sources that recognize the importance of pursuing a long-term value-added technology strategy. Problems procuring capital, particularly venture capital, are major obstacles for firms seeking growth in this sector.

Success in R&D may be a necessary condition for growth, but it is not sufficient. Firms also require a great deal of capital for marketing and distribution. They may be prudent to seek capital from their major customers and suppliers to help build credibility with the more traditional sources of capital. Executives in this sector tend to find that the traditional sources of capital are unsophisticated in assessing technical requirements and capabilities.

Business Strategy

Self-help is often the best help, and there is much this sector might do to help itself. To enhance their growth prospects, Canadian machinery firms may find it advantageous to improve their technological capability. According to a group of leading executives in the sector,[42] Canadian machinery firms should:

a) Improve their internal planning by including technology development in their business plan; do their technology planning in a cooperative, multi-functional team environment; and aim their technology improvements at developing a unique capability, rather than simply matching the competition.

b) Address the need for better technical training, to overcome the lack of people with the appropriate skills to support technological advances.

c) Consider how to cooperate with others in the private sector as well as with governments, universities, and colleges to establish research centres and form partnerships and networks of companies. This cooperation would help achieve greater competitiveness and nurture a team-based creative atmosphere.

d) Become more aware of and learn how to take advantage of the many government assistance programs.

e) Build working relationships with key customers for whom technology is a vital selling tool and from whom the company can expect useful advice, assistance, and demands for technological improvements.

f) Assess with appropriate trade associations the opportunities and support for creating a trading company to promote and help market Canadian machinery around the world.

Conclusion

The machinery sector has found it difficult to develop in Canada, despite some notable creative exceptions. In general, Canadian firms in this sector are too small to reach global threshold levels of marketing activity and technology investment.

This has a decisive negative impact on the Canadian economy; any Canadian business expansion is at risk of being throttled by a balance of payments deficit largely brought on by rapidly escalating imports of machinery goods. If there is one sector where government policy, subject to international trade agreements, should seek to act directly to obviate a major structural weakness in the economy, this may be the one.

Yet, given the current small size of the Canadian sector, the policy challenge is virtually tantamount to establishing a sector from scratch. Policy makers may find it helpful in this regard to use offshore "models" for development guidelines.

Appendix: Framework for Technology Strategies

As part of the methodology for analysing each sector, the Science Council of Canada sought whenever possible to assess company technology strategies according to the following framework:

	adopt and adapt	innovation	breakthrough
product			
process			

Strategy Classes

Adopt and adapt: Acquire a technology and adapt it to serve as a competitive platform.

Innovation: Incrementally improve on winning technology to get greater market share or maintain competitive edge.

Breakthrough: Seek to create a discontinuity in the marketplace, thereby leaping ahead of the competition.

The company case studies generally looked for at least seven key dynamics influencing a company's technology strategy:

- three internal dynamics:
  - competitive position,
  - capacity for innovation, and
  - strategy and vision; and
- four external dynamics:
  - customer demands,
  - competitive rivalry,
  - supply condition, and
  - available technology.

The methodology also incorporated essentially a three-step process for each sector. In the first step one or more contractors analysed the main elements in the competitive and R&D performance of the Canadian sector and its leading foreign competitors. The second step included evaluation of the contract report(s), discussion with contractors and other experts, additional in-house research, and preparation of a draft Council report. In the third step, external reviewers commented on one or more drafts of the Council report, which were then revised and refined as required, drawing on the advice of the liaison person for that sector on the Steering Committee (see Acknowledgements). For some sectors, the third step also involved several external reviewers in a small workshop, one part of which

helped define some elements of a potential action plan for the sector. The report was then submitted for final approval to the Executive Committee of the Science Council, before being forwarded to Industry, Science and Technology Canada.

Notes

1. Canada Consulting Cresap, *Non-Electrical Machinery*, Report prepared for the Science Council of Canada (Ottawa, 1991), 9.

2. Ibid., 92.

3. Ontario, Ministry of Education, *September School Report* (Toronto, 1988).

4. Canada Consulting Cresap, op. cit., 93.

5. Science Council of Canada, Background Study 48, *Threshold Firms: Backing Canada's Winners*, Science Council of Canada (Ottawa: Supply and Services Canada, 1982).

6. Ibid., 75.

7. F. Longo and R. Clayton, "A Simulation of the Economic Impact of Increased Industrial R&D," unpublished paper prepared for the Ministry of State for Science and Technology (Ottawa, 1986).

8. The model used was Informetrica Limited's "TIM" model.

9. Longo and Clayton, op. cit.

10. Canada Consulting Cresap, op. cit., 20.

11. Ibid.

12. Ibid., 21.

13. Ibid.

14. Ibid.

15. Ibid.

16. Ibid., 22.

17. Ibid., 23.

18. Ibid.

19. Ibid., 62.

20. Ibid., 61.

21. Ibid., 63.

22. Ibid.

23. Ibid., 67.

24. Ibid., 68.

25. Ibid., 70.

26. Ibid.

27. Ibid., 28.

28. Ibid.

29. Ibid.

30. Ibid., 31.

31. See Science Council of Canada, Sectoral Technology Strategy Series, No. 4: *The Canadian Automotive-Vehicle Sector* (Ottawa, 1991).

32. Canada Consulting Cresap, op. cit., 28.

33. Ibid., 27.

34. Ibid., 34.

35. Ibid., 80.

36. Ibid., 42.

37. Ibid., 43, 45.

38. Ibid., 46.

39. R.D. Schad, *How to Compete from a Canadian Manufacturing Base* (Bolton, Ontario: Husky Injection Molding Systems Ltd., 1990), 7.

40. Canada Consulting Cresap, op. cit., 54.

41. Giffels Associates Ltd., OCAM Division, *Report on the Technical Competitiveness Round Table of the Non-Electrical Machinery Sector*, Report prepared for the Science Council of Canada (Ottawa, 1991), 6.

42. Ibid., 10, 11.